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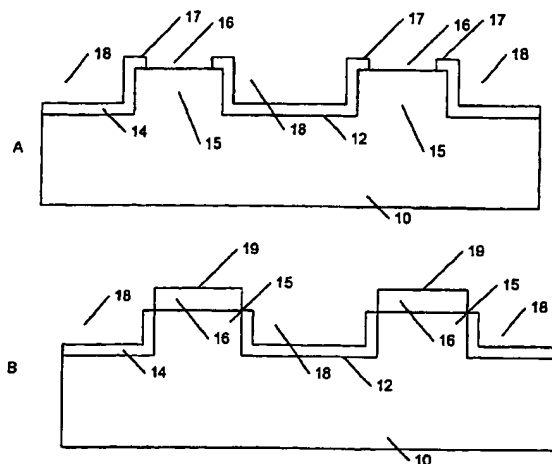
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(54) Title: SINGLE STEP PENDEO- AND LATERAL EPITAXIAL OVERGROWTH OF GROUP III-NITRIDE LAYERS



(57) Abstract: A method of fabricating a gallium nitride-based semiconductor structure on a substrate includes the steps of forming a mask (14) having at least one opening (6) therein directly on the substrate (18), growing a buffer layer (12) through the opening, and growing a layer of gallium nitride (20) upwardly from the buffer layer and laterally across the mask. During growth of the gallium nitride from the mask, the vertical and horizontal growth rates of the gallium nitride layer are maintained at rates sufficient to prevent polycrystalline material (30) nucleating on said mask from interrupting the lateral growth of the gallium nitride layer. In an alternative embodiment, the method includes forming at least one raised portion (15) defining adjacent trenches (18) in the substrate and forming a mask (14) on the substrate (10), the mask having at least one opening (16) over the upper surface of the raised portion. A buffer layer (12) may be grown from the upper surface of the raised portion. The gallium nitride layer (26) is then grown laterally by pendeoepitaxy over the trenches.

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SINGLE STEP PENDEO-AND LATERAL EPITAXIAL OVERGROWTH OF GROUP III-NITRIDE LAYERS

Field of the Invention

The present invention relates to electronic device structures and fabrication methods, and more particularly to Group III-nitride semiconductor structures and methods of fabrication by pendeo- and lateral epitaxial overgrowth.

Background

Gallium nitride (GaN) is a wide-bandgap semiconductor material widely known for its usefulness as an active layer in blue light emitting diodes. GaN is also under investigation for use in other microelectronic devices including laser diodes and high-speed, high power transistor devices. As used herein, "gallium nitride" or "GaN" refers to gallium nitride and III-nitride alloys thereof, including aluminum gallium nitride (AlGaN), indium gallium nitride (InGaN) and aluminum indium gallium nitride (AlInGaN).

High-quality bulk crystals of GaN are currently unavailable for commercial use. Thus, GaN crystals are typically fabricated as heteroepitaxial layers on underlying non-GaN substrates. Unfortunately, GaN has a considerable lattice mismatch with most suitable substrate crystals. For example, GaN has a 15% lattice mismatch with sapphire and a 3.5% lattice mismatch with silicon carbide. Lattice mismatches between a substrate and an epitaxial layer cause threading dislocations which may propagate through the growing epitaxial layer. Even when grown on silicon carbide with an aluminum nitride buffer layer, a GaN epitaxial layer exhibits dislocation densities estimated to be in excess of $10^8/\text{cm}^2$. Such defect densities limit the usefulness of GaN in highly sensitive electronic devices such as laser diodes.

Lateral Epitaxial Overgrowth (LEO) of GaN has been the subject of considerable interest since it was first introduced as a method of reducing the dislocation densities of epitaxially grown GaN films. Essentially, the technique consists of masking an underlying layer of GaN with a mask having a pattern of openings and growing the GaN

up through and laterally onto the mask. It was found that the portion of the GaN layer grown laterally over the mask exhibits a much lower dislocation density than the underlying GaN layer or the portion of the GaN layer above the mask openings. As used herein, "lateral" or "horizontal" refers to a direction generally parallel to the surface of a substrate, while the term "vertical" means a direction generally orthogonal to the surface of a substrate.

One drawback to conventional LEO techniques is that separate process steps are required for growing the underlying GaN layer, masking the GaN layer and then growing the lateral layer. Early embodiments of LEO did not place the mask directly on the non-GaN substrate because unwanted nucleation would occur on the mask during nucleation of the GaN layer at low temperatures, preventing adjacent laterally-grown regions from coalescing (or otherwise from growing laterally a desired distance if coalescence is not required). When the mask is placed directly on a GaN layer, unwanted nucleation on the mask is typically not a problem since low temperature nucleation is not required and the growth temperature of GaN is very high, typically above 1000°C. During high temperature growth, unwanted nucleation does not occur on the mask due to the much higher sticking coefficient of gallium atoms on the gallium nitride surface as compared to the mask.

This drawback is addressed with some success by a "single step" process for LEO. Shealy et al. disclosed a process whereby an underlying SiC or sapphire substrate was masked with silicon nitride. The process is referred to as "single step" because it does not require growth of an intermediate layer of GaN between the substrate and the mask. Shealy found that minimizing nucleation on the silicon nitride mask permitted growth of a relatively defect free layer of laterally-grown GaN over the masks. However, under certain circumstances it is desirable to avoid having to minimize nucleation on the mask, yet still be able to grow a relatively defect free layer of GaN in a single step process.

Object and Summary of the Invention

Accordingly, there is a need in the art for a method of fabricating a relatively defect-free single crystal film of gallium nitride in a single step process without having to
5 minimize nucleation on the mask layer.

Moreover, there is a need in the art for a method of fabricating a relatively defect-free single crystal film of gallium nitride in a single step process without having to minimize nucleation on the mask layer which provides a conductive buffer layer to permit electrical communication between a conductive substrate and an epitaxial layer of
10 gallium nitride.

It is an object of the present invention to provide a method of fabricating a relatively defect-free single crystal film of gallium nitride in a single step process without having to minimize nucleation on the mask layer.

It is a further object of the present invention to provide a method of fabricating a
15 relatively defect-free single crystal film of gallium nitride in a single step process without having to minimize nucleation on the mask layer which provides a conductive buffer layer to permit electrical communication between a conductive substrate and an epitaxial layer of gallium nitride.

The foregoing and other objects are achieved by a method of fabricating a gallium
20 nitride-based semiconductor structure on a substrate. The method includes the steps of forming a mask having at least one opening therein directly on the substrate, growing a buffer layer through said at least one opening, and growing a layer of gallium nitride upwardly from said buffer layer and laterally across said mask. During growth of the gallium nitride from the mask, the vertical and horizontal growth rates of the gallium
25 nitride layer are maintained at rates sufficient to prevent polycrystalline material nucleating on said mask from interrupting the lateral growth of the gallium nitride layer.

In an alternative embodiment, the method includes forming at least one raised portion defining adjacent trenches in the substrate and forming a mask on the substrate, the mask having at least one opening over the upper surface of the raised portion. A
30 buffer layer may be grown from the upper surface of the raised portion. The gallium nitride layer is then grown laterally by pendeoepitaxy over the trenches.

In another embodiment, the present invention provides a gallium nitride-based semiconductor structure on a substrate. The structure includes a substrate and a mask having at least one window therein applied directly on the upper surface of the substrate. An overgrown layer of gallium nitride extends upwardly from the mask window and
5 laterally across the mask, on which polycrystalline material has nucleated and grown.

In another embodiment, the substrate includes at least one raised portion defining adjacent trenches. A mask structure overlays the substrate and a window in the mask exposes at least a portion of the upper surface of the raised portion. An overgrown layer of gallium nitride extends upwardly from the mask window and laterally over the trench
10 and across the mask, on which polycrystalline material has nucleated and grown.

Brief Description of the Drawings

FIG. 1 is a cross-section of a substrate on which a mask has been patterned.

15 FIG. 2 is a plan view of a substrate on which a mask has been patterned.

FIG. 3 is a cross section of a substrate on which a layer of GaN has been epitaxially grown by LEO on a conductive buffer layer.

FIG. 3A is a cross section of a substrate on which a layer of GaN is being epitaxially grown by LEO on a conductive buffer layer, but has not coalesced.

20 FIG. 4 is a cross section of a substrate on which excessive nucleation on the mask has interrupted the lateral growth of a layer of GaN.

FIG. 5 is a cross section of a substrate on which a layer of GaN has been epitaxially grown in accordance with an aspect of the present invention.

25 FIG. 6 is a cross section of a substrate on which a layer of GaN has been epitaxially grown in accordance with another aspect of the present invention.

FIG. 6A is a cross section of a substrate on which a pair of raised portions has been formed and a mask layer has been deposited.

FIG. 6B is a cross section of a substrate on which a pair of raised portions has been formed and a mask layer has been deposited using a self-alignment technique.

30 FIG. 7 is a cross-sectional SEM image showing the interruption of lateral growth of a GaN layer by crystals nucleating on the mask.

FIG. 8 is a plan view SEM image of two GaN stripes in which crystallites on the underlying mask disturbed the epitaxial growth.

FIG. 9 is a cross-sectional SEM of GaN stripes grown in accordance with an embodiment of the present invention using a reflective mask layer.

5 FIG. 10 is a cross-sectional SEM of GaN stripes grown in accordance with an embodiment of the present invention until adjacent regions have coalesced over the reflective masks.

FIG. 11 is a cross-sectional SEM of a GaN layer grown on a conductive buffer layer over a Si_3N_4 mask.

10 FIG. 12 is a cross sectional SEM of a GaN layer grown in accordance with a second embodiment of the present invention.

FIG. 13 is a plan view SEM image of two GaN stripes grown in accordance with the second embodiment of the present invention.

15 FIG. 14 is a cross-sectional TEM (Transmission Electron Microscopy) image of a layer of GaN grown in accordance with the present invention.

FIG. 15 is a cross-sectional SEM of GaN stripes grown in accordance with an embodiment of the present invention while maintaining a ratio of lateral to horizontal growth rates of 4.2:1.

20 FIG. 16 is a cross-sectional SEM of GaN stripes grown in accordance with an embodiment of the present invention while maintaining a ratio of lateral to horizontal growth rates of 1:1.

Detailed Description of the Invention

25 The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to
30 like elements throughout. Furthermore, the various layers and regions illustrated in the figures are illustrated schematically. As will also be appreciated by those of skill in the

art, references herein to a layer formed "on" a substrate or other layer may refer to the layer formed directly on the substrate or other layer or on an intervening layer or layers formed on the substrate or other layer. References herein to a layer formed "directly on" a substrate or other layer refer to the layer formed on the substrate without an intervening layer or layers formed on the substrate or other layer. The present invention is not limited to the relative size and spacing illustrated in the accompanying figures.

Basic LEO techniques are described in A. Usui, et al., "Thick GaN epitaxial growth with low dislocation density by hydride vapor phase epitaxy," Jpn. J. Appl. Phys. Vol. 36, pp. L899-902 (1997). Various LEO techniques including pendeoepitaxial techniques are described in U.S. Application Serial No. 09/032,190 "Gallium Nitride Semiconductor Structures Including a Lateral Gallium Nitride Layer that Extends From an Underlying Gallium Nitride Layer", filed February 27, 1998; Application Serial No. 09/031,843 "Gallium Nitride Semiconductor Structures Including Laterally Offset Patterned Layers", filed February 27, 1998; Application Serial No. 09/198,784, "Pendeoepitaxial Methods of Fabricating Gallium Nitride Semiconductor Layers on Silicon Carbide Substrates by Lateral Growth from Sidewalls of Masked Posts, and Gallium Nitride Semiconductor Structures Fabricated Thereby" filed November 24, 1998; and Application Serial No. 60/088,761 "Methods of Fabricating Gallium Nitride Semiconductor Layers by Lateral Growth from Sidewalls into Trenches, and Gallium Nitride Semiconductor Structures Fabricated Thereby," filed June 10, 1998, the disclosures of each of which are hereby incorporated herein by reference.

Referring now to FIG. 1, a substrate 10 is illustrated on which is deposited a mask layer 14 comprising stripes 14a and 14b. Although the stripe pattern may continue in a periodic or aperiodic fashion on either side, for convenience only stripes 14a and 14b are illustrated. Stripes 14a, 14b are characterized in that they have a width (w) and are separated by mask openings or windows 6 having a window length (l). The distance between an edge of stripe 14a and the corresponding edge of stripe 14b is defined as the period (p) of the mask pattern, at least with respect to stripes 14a and 14b, such that $p=w+l$.

The mask layer may be deposited using plasma enhanced chemical vapor deposition (PECVD), sputtering, electron-beam deposition, thermal oxidation or other

deposition techniques, and patterned using standard photolithographic techniques. The PECVD process is described in detail in Chapter 6 of S.M. Sze, *VLSI Technology*, 2nd ed., McGraw-Hill 1988. Photolithographic techniques are well known in the art.

As illustrated in FIG. 2, stripes 14a and 14b are preferably oriented along the
5 $\langle 1\bar{1}00 \rangle$ crystallographic direction in the (0001) plane. (Crystallographic designation conventions used herein are well known in the art and need not be described further.) The mask layer 14 may comprise silicon nitride (Si_xN_y) or silicon dioxide (SiO_2) or any other suitable mask material. If the structure being fabricated is intended for use in an optical device such as an LED or laser diode, the mask layer 14 may comprise a
10 reflective or refractory metal which is stable in ammonia and hydrogen gas, has a melting point in excess of about 1200°C, and is reflective to the desired wavelength. Examples of such metals include tungsten (W) and platinum (Pt). Alternatively, the mask layer could comprise a Bragg reflector which may comprise alternating layers of Si_xN_y and SiO_2 or other oxides, the design of which is well known in the art.

15 The substrate may be silicon carbide, sapphire (Al_2O_3), silicon, ZnO, or any other similarly suitable substrate. Silicon carbide substrates are advantageous for a number of reasons. Silicon carbide provides closer lattice and thermal expansion matches for GaN, is thermally and chemically stable, has natural cleave planes, high thermal conductivity, and is transparent to visible wavelengths up to 380 nm. Also, silicon carbide has a
20 distinct advantage in that it is conductive, which permits fabrication of vertical-geometry devices. Silicon carbide substrates may have a polytype of 4H, 6H, 3C or 15R. Preferably, however, the substrate is 6H-SiC (on-axis).

The fabrication of substrate 10 is well known to those in the art. Fabrication of silicon carbide substrates are described, for example, in U.S. Patents 4,865,685 to
25 Palmour et al., Re34,861 to Davis, et al., 4,912,064 to Kong et al., and 4,946,547 to Palmour et al., the disclosures of each of which are hereby incorporated by reference. The fabrication of sapphire and silicon substrates is well known in the art and need not be described in detail.

Referring now to FIG. 3, an epitaxial layer 20 may be fabricated by first growing
30 a buffer layer 12 on the surface of the substrate 10. Epitaxial layer 20 may comprise gallium nitride or a Group III-nitride alloy thereof, such as aluminum gallium nitride

(AlGaIn), indium gallium nitride (InGaIn), or aluminum indium gallium nitride (AlInGaIn). For a SiC substrate, the buffer layer preferably comprises a layer 12 of $\text{Al}_x\text{Ga}_{1-x}\text{N}$, where x represents the mole fraction of aluminum present in the alloy and $0 < x \leq 1$. In the case of silicon carbide substrates, the buffer layer 12 may have the structure described in copending and commonly assigned U.S. Patent Application Serial No. 08/944,547 entitled "Group III Nitride Photonic Devices on Silicon Carbide Substrates with Conductive Buffer Interlayer Structure," filed October 7, 1997, the disclosure of which is hereby incorporated herein by reference.

Preferably, the topmost buffer layer comprises a mole percentage of Al of between 9% and 12%, and is approximately 1000 to 5000 Å thick. The buffer layer 12 may be made conductive to the SiC substrate by the formation of capped GaN dots on the SiC substrate as described in U.S. Patent Application Serial No. 08/944,547 prior to the deposition of the buffer layer.

For sapphire or silicon substrates, a low temperature GaN, AlN or AlGaIn buffer may be grown.

As shown in FIG. 3, an AlGaIn buffer layer 12 may be grown vertically from the mask openings 6 using a vapor phase epitaxy (VPE) technique such as hydride vapor phase epitaxy (HVPE), or more preferably metal-organic vapor phase epitaxy (MOVPE). In a preferred embodiment, the buffer layer 12 is grown to a thickness larger than the thickness of the mask layer 14. Once the buffer layer 12 has been grown to a desired thickness, the epitaxial layer 20 is then grown by VPE, preferably in the same run or step as the buffer layer was grown.

As shown in FIG. 3A, epitaxial layer 20 grows laterally (i.e. parallel to the face of the substrate) in addition to vertically. Lateral growth fronts 22 move across the surface of the mask stripes 14 as layer 20 grows.

Referring again to FIG. 3, in one embodiment, epitaxial layer 20 grows laterally until the growth fronts 22 coalesce at interfaces 24 to form a continuous layer 20 of gallium nitride. However, it is not necessary for the growth fronts to coalesce for all applications, as it is possible to fabricate devices in laterally overgrown portions of GaN even if they have not coalesced with adjacent portions. As illustrated in FIG. 9, a useful portion of layer 20 may be fabricated without coalescence of adjacent portions. For

example, a laser diode stripe may be fabricated in a region of layer 20 that has not coalesced. For fabrication of an LED, a coalesced layer is preferred. For example, an LED device 250μ wide and 275μ long may be fabricated on a coalesced layer of gallium nitride grown in accordance with the present invention.

5 The buffer layer 12 and the overgrown layer 20 may be grown using trimethylgallium (TMG), trimethylaluminum (TMA) and ammonia (NH_3) precursors in a diluent of H_2 . A suitable MOVPE growth technique is described in greater detail in T. Weeks et al., "*GaN thin films deposited via organometallic vapor phase epitaxy on $\alpha(6H)\text{-SiC}(0001)$ using high-temperature monocrystalline AlN buffer layers,*" Appl. Phys. Lett., Vol. 67, No. 3, July 1995, pp. 401-403.

10 While the layer 20 of gallium nitride is growing, nucleation and growth of polycrystalline $\text{Al}_x\text{Ga}_{1-x}\text{N}$ 30 typically begins to occur on the exposed upper surfaces of mask stripes 14. As illustrated in FIG. 4, if the growth rate of $\text{Al}_x\text{Ga}_{1-x}\text{N}$ on the masks is too high, the lateral growth of layer 20 will be interrupted, preventing it from forming a
15 desired width of laterally overgrown material, and/or preventing it from coalescing with adjacent regions. Essentially, the polycrystalline $\text{Al}_x\text{Ga}_{1-x}\text{N}$ 30 on the mask grows vertically and blocks the lateral growth of the single crystal layer 20.

20 The present inventors have discovered that it is possible, by controlling the horizontal and vertical growth rates of layer 20, to avoid interruption of the laterally growing layer 20 by the polycrystalline $\text{Al}_x\text{Ga}_{1-x}\text{N}$ 30. By increasing the lateral growth rate of layer 20 relative to its vertical growth rate by a given amount depending on the geometry of the structure, it is possible to grow a layer 20 that will grow to a desired distance despite nucleation on the mask.

25 Stated differently, by maintaining a sufficiently high lateral growth rate relative to the vertical growth rate of layer 20, nucleation on the mask need not be controlled, since layer 20 will overgrow any polycrystalline nucleation and growth on the mask.

30 As a particular example, it has been discovered that by maintaining a ratio of lateral growth rate to vertical growth rate of at least 1:1, it is possible to grow a laterally-overgrown GaN layer on a stripe having a width of 5μ in a pattern with a period of 30μ from a nucleation layer having an Al concentration of about 10%. By maintaining a lateral/vertical growth ratio of 4:1, it is possible to grow a layer of GaN over a mask

having 25 μ -wide stripes. As shown in FIG. 5, when the lateral growth rate is caused to exceed the vertical growth rate by a sufficient amount, the growth fronts of the layer 20 may coalesce before the polycrystalline AlGaIn growing on the stripes 14a,b grow large enough to block them.

5 The mechanisms for controlling the relevant growth factors will now be described in detail. The lateral and vertical growth rates of the overgrown layer 20 are controlled by a number of factors. One controlling factor is the so called "fill factor", defined herein as the ratio of the window length (l) to the stripe period (p). For a given window length, a higher fill factor (i.e. a larger window length for a given period) results in a slower
10 vertical growth rate. Conversely, for a given window length, a lower fill factor results in an increased vertical growth rate. Other factors for controlling the lateral and vertical growth rates are growth temperature, source gas flow rates, source gas nitrogen/gallium ratio, and growth pressure.

 If desired, once the laterally growing growth fronts 22 of the layer 20 have
15 coalesced over the masks, the growth conditions can be adjusted to increase the vertical growth rate.

 Although dependent on the structure of the particular epitaxial growth reactor being employed, typical growth parameters for the rates described herein are summarized in the following table.

20

Parameter	Value
Growth temperature	1060-1120°C
Growth pressure	50-200 Torr
N/Ga ratio	2500
Fill factor	0.714 - 0.833
Lateral growth rate/vertical growth rate	1 - 4.2

Table 1 - Typical growth parameters.

 Preferably, a lateral growth rate of about 2-8 μ /hr and a vertical growth rate of about 1-2 μ /hr should be selected. A lateral growth rate of 6.3 μ /hr and a vertical growth rate of 1.5 μ /hr (4.2:1 ratio) may be achieved by growing the layer 20 by MOVPE at
25 1110°C and 200 Torr on a patterned mask of Si_xN_y stripes having a stripe width of 10 μ , a

window width of 25μ and a period of 35μ for a fill factor of 0.71. The N/Ga ratio during growth of the layer 20 is preferably about 2500. Ratios of lateral growth rate to vertical growth rate may exceed 4.2:1.

To grow the buffer layer, TMG may be flowed at $34.8\mu\text{mol/min}$, TMA may be
5 flowed at $6.5\mu\text{mol/min}$ and ammonia may be flowed at a rate of 10 slpm in a diluent of H_2 at 15.5 slpm. Once the buffer layer has been grown to a desired thickness, the layer 20 may be grown by flowing TMG at $309\mu\text{mol/min}$ and ammonia at a rate of 17 slpm in a diluent of H_2 at 22.5 slpm until the GaN layer has grown to a desired thickness.

A lateral and vertical growth rate of $4.2\mu/\text{hr}$ (1:1 ratio) may be achieved by
10 growing the layer 20 by MOVPE at 1060°C and 200 Torr on a patterned mask of Si_xN_y stripes having a stripe width of 10μ , a window length of 25μ and a period of 35μ for a fill factor of 0.71. The N/Ga ratio during growth of the layer 20 is preferably about 2500. It will be appreciated that other ratios, including ratios greater than 4.2:1, may be achieved through selection of other growth parameters.

15 An embodiment of the present invention utilizing pendeoepitaxial growth is illustrated in FIG. 6. In this embodiment, the substrate 10 is etched to form at least one raised portion 15, which defines adjacent recessed areas or trenches 18 on the substrate 10. FIG. 6 illustrates an embodiment in which a pair of raised portions 15a, 15b have been patterned using standard photolithographic techniques and reactive ion etching.
20 Preferably, the height of raised portions 15 (i.e. the depth of trenches 18) is at least 1μ . A mask layer 14, which may be Si_xN_y , SiO_2 or any other suitable mask is then deposited on the upper surface of substrate 10, with mask openings 16 made on the upper surfaces of raised portions 15a, 15b.

In this embodiment, the substrate 10 may be silicon carbide, sapphire, silicon,
25 gallium arsenide, gallium nitride or another Group III-nitride such as aluminum nitride or aluminum gallium nitride. The fabrication of aluminum nitride substrates is described in U.S. Patent No. 5,858,086 and 5,954,874 to Hunter, the disclosures of which are hereby incorporated herein by reference. Gallium nitride substrates have been fabricated by growing thick epitaxial layers of gallium nitride on a non-GaN substrate. Other methods
30 of obtaining gallium nitride substrates are summarized in A. Usui, et al., "Thick GaN epitaxial growth with low dislocation density by hydride vapor phase epitaxy," Jpn. J.

Appl. Phys. Vol. 36, pp. L899-902 (1997). It will be appreciated by those of skill in the art that when the substrate is a Group III-nitride, homoepitaxial growth may be used.

As shown in FIG. 6, if a buffer layer is required, an AlGa_N buffer layer 12 may be grown vertically from the mask openings (or windows) 16 using MOVPE. In a preferred embodiment, the buffer layer 12 is grown to a thickness larger than the thickness of the mask layer 14. Once the buffer layer 12 has been grown to a desired thickness, the pendeoepitaxial layer 26 is then grown. Pendeoepitaxial layer 26 grows laterally (i.e. parallel to the face of the substrate) over trenches 18 in addition to vertically.

Although nucleation and growth of polycrystalline GaN 30 may be occurring on the mask 14, it is occurring within trenches 18, and thus does not interfere with the lateral growth of pendeoepitaxial layer 26.

FIG. 12 is a cross sectional SEM of a pendeoepitaxial GaN layer grown in accordance with this embodiment of the invention. Polycrystalline AlGa_N material is evident within the trench, but does not interfere with the lateral growth of the GaN layer.

It will be readily appreciated that a trench depth of 1 μ is exemplary. Trenches 18 may be fabricated with depths less than or greater than 1 μ if desired or necessary depending on the rate of polycrystalline growth on the mask or the width of the pendeoepitaxial layer to be grown.

In one embodiment, pendeoepitaxial layer 26 grows laterally until opposing growth fronts 22 coalesce at interfaces 24 to form a continuous layer 26 of gallium nitride. However, as mentioned above, it is not necessary for the growth fronts 22 to coalesce for all applications, as it is possible to fabricate devices in laterally overgrown portions of GaN even if they have not coalesced with adjacent portions.

FIG. 13 is a plan view SEM image of two pendeoepitaxial GaN stripes grown in accordance with this embodiment of the present invention.

For the embodiment illustrated in FIG. 6, alternative methods of forming the mask layer 14 are illustrated in FIGs 6A and 6B. As discussed above, raised portions 15 may be formed using standard etching techniques. Typically, this involves patterning the surface of a substrate with an etch mask, etching the substrate to the desired depth, and then removing the etch mask. As shown in FIG. 6A, after the etch mask has been

removed, the mask layer 14 may be formed on the surface of substrate 10 by PECVD. Windows 16 are then opened in mask 14 to reveal the upper surfaces of raised portions 15.

Because of the tolerance limitations of photolithographic techniques, when the windows 16 are opened in mask 14, it is difficult to align the edges of windows 16 with the edges of raised portions 15. Thus, there is some overlap 17 of the mask 14 onto the upper surfaces of raised portions 15.

A simplified method of forming mask 14 is illustrated in FIG. 6B. In this method, an etch mask 19 is applied to the surface of substrate 10, and substrate 10 is etched to form trenches 18. Mask 14 is deposited after etching trenches 18 but prior to removing etch mask 19. In this technique, mask 14 preferably comprises a thin mask layer of about 50-200 Å in thickness. Mask 14 may comprise Si_xN_y , SiO_2 , or any other suitable mask material. Etch mask 19 is then removed, revealing the upper surfaces of raised portions 15. The edges of windows 16 in mask 14 are thereby self-aligned with the edges of raised portions 15. Thus, with this technique, only a single masking step is required and it is not necessary to use photolithographic techniques to open windows 16 in mask layer 14.

FIG. 7 is a cross-sectional SEM image showing the interruption of lateral growth of a GaN layer by crystals nucleating on the mask.

FIG. 8 is a plan view SEM image of two GaN stripes in which crystallites on the underlying mask disturbed the epitaxial growth.

FIG. 9 is a cross-sectional SEM of GaN stripes grown in accordance with an embodiment of the present invention using a reflector mask layer.

FIG. 10 is a cross-sectional SEM of GaN stripes grown in accordance with an embodiment of the present invention until adjacent regions have coalesced over the masks.

FIG. 11 is a cross-sectional SEM of a GaN layer grown on a conductive buffer layer over a Si_3N_4 mask.

FIG. 14 is a cross-sectional TEM (Transmission Electron Microscopy) image of a layer of GaN grown in accordance with the present invention. The defect densities

observed indicate an estimated reduction from approximately $10^9/\text{cm}^2$ in the regions over the windows to approximately $10^6/\text{cm}^2$ in the regions above the mask stripes.

Example 1:

5 A patterned mask of Si_xN_y stripes having a stripe width of 10μ , a window length of 25μ and a period of 35μ for a fill factor of 0.715 was applied to a 6H-SiC substrate. The stripes were arranged parallel to the $\langle 1\bar{1}00 \rangle$ direction. A 0.5μ thick $\text{Al}_{0.1}\text{Ga}_{0.9}\text{N}$ buffer layer was grown by MOVPE by flowing TMG at $34.8\mu\text{mol}/\text{min}$, TMA at $6.5\mu\text{mol}/\text{min}$ and ammonia at 10 slpm in a diluent of H_2 at 15.5 slpm at 1020°C and 76 Torr for a total of 80 minutes. Following growth of the buffer layer, an epitaxial layer of GaN was grown by MOVPE by flowing TMG at $309\mu\text{mol}/\text{min}$ and ammonia at 17 slpm in a diluent of H_2 at 22.5 slpm at 1110°C and 200 Torr for 45 minutes. The ratio of lateral to vertical growth under these conditions was approximately 4.2:1. FIG. 15 is an SEM image a cross section of the resulting GaN layer.

15

Example 2:

 A patterned mask of Si_xN_y stripes having a stripe width of 10μ , a window length of 25μ and a period of 35μ for a fill factor of 0.715 was applied to a 6H-SiC substrate. The stripes were arranged parallel to the $\langle 1\bar{1}00 \rangle$ direction. A 0.5μ thick $\text{Al}_{0.1}\text{Ga}_{0.9}\text{N}$ buffer layer was grown by MOVPE by flowing TMG at $34.8\mu\text{mol}/\text{min}$, TMA at $6.5\mu\text{mol}/\text{min}$ and ammonia at 10 slpm in a diluent of H_2 at 15.5 slpm at 1050°C and 76 Torr for a total of 80 minutes. Following growth of the buffer layer, an epitaxial layer of GaN was grown by MOVPE by flowing TMG at $309\mu\text{mol}/\text{min}$ and ammonia at 17 slpm in a diluent of H_2 at 22.5 slpm at 1060°C and 200 Torr for one hour. The ratio of lateral to vertical growth under these conditions was approximately 1:1. FIG. 16 is an SEM image a cross section of the resulting GaN layer.

25

 In the specification and drawings, there have been set forth preferred and exemplary embodiments of the invention which have been included by way of example and not by way of limitation, the scope of the invention being set forth in the accompanying claims.

30

1. A method of fabricating a gallium nitride-based semiconductor structure on a substrate, the method comprising:

forming a mask having an opening on said substrate;

growing an epitaxial layer selected from the group consisting of gallium nitride
5 and Group III nitride alloys of gallium nitride vertically from the opening and laterally across the mask; and

maintaining the lateral growth rate of said epitaxial layer at a rate sufficient to prevent polycrystalline nitride material nucleating on the mask from interrupting the lateral growth of said epitaxial layer.

10

2. A fabrication method according to Claim 1 comprising maintaining the lateral growth rate greater than the vertical growth rate.

3. A fabrication method according to Claim 1 comprising maintaining the ratio of
15 the lateral growth rate to the vertical growth rate greater than about 1:1.

4. A fabrication method according to Claim 1 comprising maintaining the ratio of the lateral growth rate to the vertical growth rate at between about 1:1 and 4.2:1.

20 5. A fabrication method according to Claim 1 comprising maintaining the ratio of the lateral growth rate to the vertical growth rate greater than about 4.2:1.

6. A fabrication method according to Claim 3 comprising maintaining the lateral growth rate at between about 2 and 8 microns per hour.

25

7. A fabrication method according to Claim 1 wherein the substrate comprises silicon carbide.

8. A fabrication method according to claim 1, further comprising:
30 growing a buffer layer through the opening in the mask, wherein said buffer layer will support the epitaxial growth of Group III nitrides thereon.

9. A fabrication method according to Claim 8 wherein the step of growing the buffer layer comprises growing a layer of $\text{Al}_x\text{Ga}_{1-x}\text{N}$ where $0 \leq x \leq 1$.

5

10. A fabrication method according to Claim 9 wherein the buffer layer forms a conductive interface to the substrate.

11. A method of fabricating a gallium nitride-based semiconductor structure on a substrate, the method comprising:

10

forming a mask having an opening therein on a substrate;

growing an epitaxial layer selected from the group consisting of gallium nitride and Group III nitride alloys of gallium nitride vertically from the opening and laterally across the mask under conditions such that polycrystalline nitride material is not inhibited from nucleating on the mask;

15

wherein the laterally growing epitaxial layer overgrows the polycrystalline nitride material.

12. A fabrication method according to Claim 11 comprising maintaining the lateral growth rate greater than the vertical growth rate.

20

13. A fabrication method according to Claim 11 comprising maintaining the ratio of the lateral growth rate to the vertical growth rate greater than about 1:1.

14. A fabrication method according to Claim 11 comprising maintaining the ratio of the lateral growth rate to the vertical growth rate at between about 1:1 and 4.2:1.

25

15. A fabrication method according to Claim 11 comprising maintaining the ratio of the lateral growth rate to the vertical growth rate greater than about 4.2:1.

30

16. A fabrication method according to Claim 13 comprising maintaining the lateral growth rate at between about 2 and 8 microns per hour.

17. A fabrication method according to Claim 11 wherein growth of the epitaxial
5 layer is performed at about 1060 to 1120 °C.

18. A fabrication method according to Claim 11 comprising forming the mask on a silicon carbide substrate.

10 19. A fabrication method according to Claim 18 comprising forming a striped mask oriented along the $\overline{<1100>}$ direction on the (0001) surface of the SiC substrate.

20. A fabrication method according to claim 11, further comprising:
growing a buffer layer through the opening in the mask, wherein said
15 buffer layer will support the epitaxial growth of Group III nitrides thereon.

21. A fabrication method according to Claim 20 wherein the step of growing the buffer layer comprises growing a layer of $\text{Al}_x\text{Ga}_{1-x}\text{N}$ where $0 \leq x \leq 1$.

20 22. A fabrication method according to Claim 21 wherein the buffer layer forms a conductive interface to the substrate.

23. A fabrication method according to Claim 20 comprising growing the buffer layer to a thickness greater than the thickness of the mask.

25

24. A fabrication method according to Claim 11 comprising growing the epitaxial layer by vapor phase epitaxy using one or more source gases selected from the group consisting of trimethyl gallium, trimethyl aluminum, and ammonia.

25. A fabrication method according to Claim 11 comprising forming a mask that includes a plurality of openings and growing the buffer and epitaxial layers from a plurality of the openings.

5 26. A fabrication method according to Claim 25 comprising growing the epitaxial layer until laterally growing portions coalesce.

27. A method of fabricating a gallium nitride-based semiconductor structure on a substrate, the method comprising:

10 forming a mask having at least two openings therein on a substrate;
 growing a buffer layer on the substrate within the openings in the mask; and
 growing an epitaxial layer selected from the group consisting of gallium nitride and Group III nitride alloys of gallium nitride upwardly from the buffer layer and laterally across the mask;

15 while maintaining the horizontal growth rate of the gallium nitride layer at a rate sufficient to prevent polycrystalline material nucleating on the mask from interrupting the lateral growth of the gallium nitride layer until the lateral growth from the openings coalesces; and

 thereafter continuing to grow the epitaxial layer vertically.

20 28. A fabrication method according to claim 27, further comprising:
 after the lateral growth from the openings coalesces, increasing the rate of vertical growth of the coalesced epitaxial layer.

25 29. A fabrication method according to Claim 27 comprising maintaining the lateral growth rate greater than the vertical growth rate.

30 30. A fabrication method according to Claim 29 comprising maintaining the ratio of the lateral growth rate to the vertical growth rate greater than about 1:1.

31. A fabrication method according to Claim 29 comprising maintaining the ratio of the lateral growth rate to the vertical growth rate at between about 1:1 and 4.2:1.

32. A fabrication method according to Claim 29 comprising maintaining the ratio
5 of the lateral growth rate to the vertical growth rate greater than about 4.2:1.

33. A fabrication method according to Claim 30 comprising maintaining the lateral growth rate at between about 2 and 8 microns per hour.

10 34. A fabrication method according to Claim 27 comprising masking the substrate using a technique selected from the group consisting of plasma-enhanced chemical vapor deposition, sputtering, reactive sputtering, electron-beam deposition and thermal oxidation.

15 35. A fabrication method according to Claim 27 comprising masking a SiC substrate.

36. A fabrication method according to Claim 27 wherein the step of growing the buffer layer comprises growing a layer of $\text{Al}_x\text{Ga}_{1-x}\text{N}$ where $0 \leq x \leq 1$.

20 37. A fabrication method according to Claim 36 wherein the buffer layer forms a conductive interface to the substrate.

38. A fabrication method according to Claim 36 comprising growing the buffer
25 layer by vapor phase epitaxy using trimethyl gallium, trimethyl aluminum, and ammonia as the source gases.

39. A fabrication method according to Claim 27 comprising growing the buffer layer to a thickness greater than the thickness of the mask.

30

40. A fabrication method according to Claim 27 comprising growing the epitaxial layer by vapor phase epitaxy using one or more source gases selected from the group consisting of trimethyl gallium, trimethyl aluminum, and ammonia.

5 41. A method of fabricating a gallium nitride-based semiconductor structure on a substrate, the method comprising:

 forming a mask on a substrate that includes both at least one trench and at least one raised portion adjacent the trench, and with the mask having at least one opening therein on the raised portion of the substrate;

10 growing a buffer layer on the raised portion of the substrate within the opening in the mask; and

 growing an epitaxial layer selected from the group consisting of gallium nitride and Group III nitride alloys of gallium nitride upwardly from the buffer layer and laterally across the trench.

15

 42. A fabrication method according to Claim 41 comprising growing the buffer layer to a thickness greater than the thickness of the mask.

 43. A fabrication method according to Claim 41 comprising forming at least two
20 raised portions adjacent to the trench and growing the epitaxial layer until it coalesces over the trench.

 44. A fabrication method according to Claim 41 wherein the step of forming the mask comprises forming the mask and then forming the opening therein.

25

 45. A fabrication method according to Claim 41 comprising forming the mask on a silicon carbide substrate.

 46. A method of fabricating a gallium nitride-based semiconductor structure on a
30 substrate, the method comprising:

forming at least one trench in a substrate to thereby define both the trench and a raised portion immediately adjacent the trench;

forming a mask on the trenched substrate with the mask having at least one opening therein on the raised portion of the substrate;

5 growing a buffer layer on the raised portion of the substrate through the opening in the mask; and

growing an epitaxial layer selected from the group consisting of gallium nitride and Group III nitride alloys of gallium nitride upwardly from the buffer layer and laterally across the trench

10

47. A fabrication method according to Claim 46 wherein the step of forming the trench comprising etching the trench in the substrate.

48. A fabrication method according to Claim 47 wherein the etching step
15 comprises a reactive ion etch.

49. A fabrication method according to Claim 46 wherein the step of forming the buffer comprises forming the buffer using vapor phase epitaxy.

20 50. A fabrication method according to Claim 46 comprising growing the buffer layer to a thickness greater than the thickness of the mask.

51. A fabrication method according to Claim 46 comprising forming at least two raised portions adjacent to the trench and growing the epitaxial layer until it coalesces
25 over the trench portion.

52. A fabrication method according to Claim 46 wherein the step of forming the mask comprises forming the mask and then forming the opening therein.

30 53. A fabrication method according to Claim 46 comprising forming the mask using a technique selected from the group consisting of plasma-enhanced chemical vapor

deposition, sputtering, reactive sputtering, electron-beam deposition and thermal oxidation.

54. A method of fabricating a gallium nitride-based semiconductor device on a
5 silicon carbide substrate, the method comprising:

etching a plurality of substantially parallel trenches in a silicon carbide substrate
that define respective raised portions of the substrate therebetween;

masking the trenched substrate;

opening a plurality of windows in the mask on the raised portions of the substrate;

10 growing a buffer layer vertically in the windows on the raised portions; and

growing an epitaxial layer selected from the group consisting of gallium nitride
and Group III nitride alloys of gallium nitride vertically and laterally from the buffer
layer and extending across a plurality of the trenches.

15 55. A fabrication method according to Claim 54 comprising maintaining the
vertical and horizontal growth rates of the gallium nitride layer at rates sufficient to
prevent polycrystalline material that may nucleate on the mask from interrupting the
lateral growth of the gallium nitride layer.

20 56. A fabrication method according to Claim 55 comprising maintaining the
lateral growth rate equal to or greater than the vertical growth rate.

57. A fabrication method according to Claim 55 comprising maintaining the ratio
of the lateral growth rate to the vertical growth rate greater than about 1:1.

25

58. A fabrication method according to Claim 55 comprising maintaining the ratio
of the lateral growth rate to the vertical growth rate at between about 1:1 and 4.2:1.

59. A fabrication method according to Claim 55 comprising maintaining the ratio
30 of the lateral growth rate to the vertical growth rate greater than about 4.2:1.

60. A fabrication method according to Claim 57 comprising maintaining the lateral growth rate at between about 2 and 8 microns per hour.

61. A fabrication method according to Claim 54 comprising masking the substrate using a technique selected from the group consisting of plasma-enhanced chemical vapor deposition, sputtering, reactive sputtering, electron-beam deposition and thermal oxidation.

62. A fabrication method according to Claim 54 comprising masking the (0001) surface of the SiC substrate along the $\langle \bar{1}100 \rangle$ direction.

63. A fabrication method according to Claim 54 wherein the step of growing the buffer layer comprises growing a layer of $\text{Al}_x\text{Ga}_{1-x}\text{N}$ where $0 \leq x \leq 1$.

64. A fabrication method according to Claim 63 wherein the buffer layer forms a conductive interface to the substrate.

65. A fabrication method according to Claim 63 comprising growing the buffer layer by vapor phase epitaxy using trimethyl gallium, trimethyl aluminum, and ammonia as the source gases.

66. A fabrication method according to Claim 54 comprising growing the buffer layer to a thickness greater than the thickness of the mask.

67. A fabrication method according to Claim 54 comprising growing the epitaxial layer by vapor phase epitaxy using one or more source gases selected from the group consisting of trimethyl gallium, trimethyl aluminum, and ammonia.

68. A method according to Claim 54 comprising opening the windows following the step of forming the mask.

69. A method according to Claim 54 comprising forming the windows while masking the trenched substrate.

70. A semiconductor structure comprising:

5 a substrate having an upper surface;

a mask directly on said upper surface of said substrate, and having at least one window therein; and

an overgrown epitaxial layer selected from the group consisting of gallium nitride and Group III nitride alloys of gallium nitride and extending upwardly from said mask window and laterally across said mask;

10 wherein polycrystalline material has nucleated on said mask.

71. A semiconductor structure according to Claim 70 wherein said mask comprises a refractory metal.

15 72. A semiconductor structure according to Claim 70 wherein said mask is reflective.

73. A semiconductor structure according to Claim 70 wherein said mask is a Bragg reflector.

74. A semiconductor structure according to Claim 70 wherein said mask is selected from the group consisting of Si_xN_y , SiO_2 , platinum and tungsten.

25 75. A semiconductor structure according to Claim 70 wherein said substrate is selected from the group consisting of silicon carbide, sapphire, silicon, gallium arsenide and zinc oxide.

76. A semiconductor structure according to Claim 70 wherein said substrate is silicon carbide and has a polytype selected from the group consisting of the 4H, 6H, 3C and 15R polytypes.

77. A semiconductor structure according to Claim 70 and further comprising a buffer layer between said substrate and said epitaxial layer.

5 78. A fabrication method according to Claim 77 wherein the buffer layer forms a conductive interface to the substrate.

79. A semiconductor structure according to Claim 77 wherein said substrate comprises sapphire and said buffer layer is formed of $\text{Al}_x\text{Ga}_{1-x}\text{N}$ where $0 \leq x \leq 1$.

10 80. A semiconductor structure according to Claim 70 comprising a plurality of windows in said mask.

81. A semiconductor structure according to Claim 80 wherein said epitaxial layer
15 is coalesced between said windows.

82. A gallium-nitride based semiconductor structure comprising:

a substrate having an upper surface and at least two raised portions of said upper surface that define at least one trench therebetween;

20 a mask structure that overlays said substrate, said mask structure having a window that exposes at least a portion of said upper surface of said raised portion of said substrate; and

an overgrown epitaxial layer selected from the group consisting of gallium nitride and Group III nitride alloys of gallium nitride extending upwardly from said mask
25 windows and laterally over said trench and across said mask .

83. A semiconductor structure according to Claim 82 comprising nucleated polycrystalline material on said mask.

30 84. A semiconductor structure according to Claim 82 wherein said nucleated polycrystalline material is in said trench.

85. A semiconductor structure according to Claim 82 wherein said substrate is selected from the group consisting of silicon carbide, sapphire, silicon, gallium arsenide and zinc oxide.

5

86. A semiconductor structure according to Claim 85 wherein said substrate is selected from the group consisting of silicon carbide and sapphire and wherein said structure further comprises a buffer between said substrate and said epitaxial layer.

10

87. A semiconductor substrate according to Claim 82 wherein said mask comprises Si_xN_y .

88. A semiconductor structure according to Claim 82 wherein portions of said epitaxial layer portions are coalesced over said at least one trench.

15

89. A semiconductor structure according to Claim 82 comprising a buffer layer on said substrate in said window in said mask.

20

90. A semiconductor structure according to Claim 82 comprising a plurality of trenches, a plurality of raised portions with at least two of said raised portions having said windows therein.

25

91. A semiconductor structure comprising:
a silicon carbide substrate having an upper surface;
a Si_xN_y mask directly on said upper surface of said substrate, and having at least one window therein;
a buffer layer of $\text{Al}_x\text{Ga}_{1-x}\text{N}$ where $0 \leq x \leq 1$ within said mask window; and
an overgrown epitaxial layer selected from the group consisting of gallium nitride and Group III nitride alloys of gallium nitride and extending upwardly from said mask window and laterally across said mask;
wherein polycrystalline material has nucleated on said mask.

30

92. A gallium-nitride based semiconductor structure comprising:

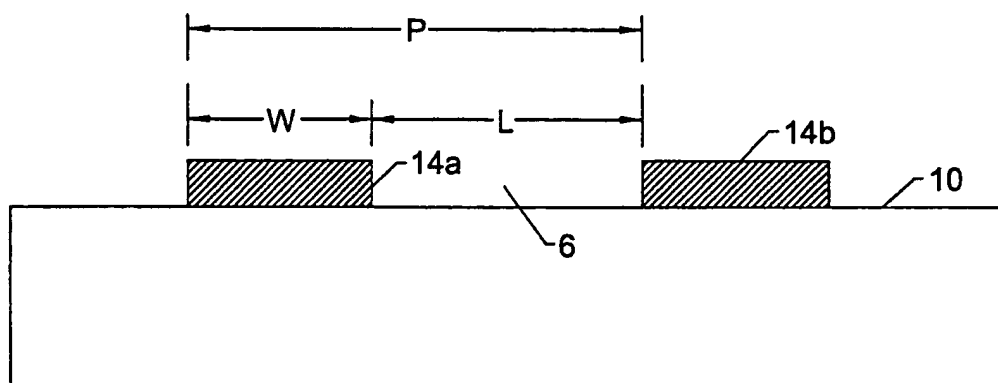
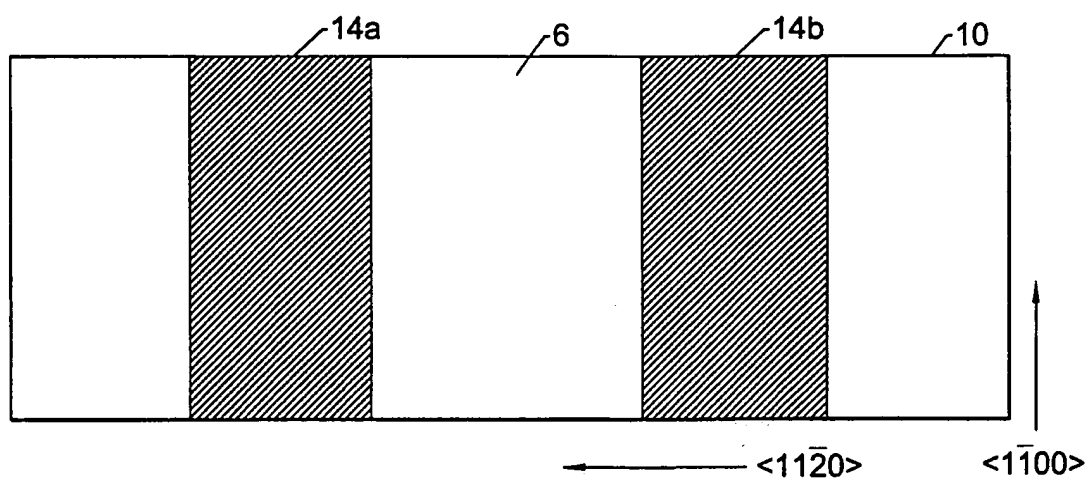
a silicon carbide substrate having an upper surface and at least two raised portions of said upper surface that define at least one trench therebetween;

5 a Si_xN_y mask structure that overlays said substrate, said mask structure having a window that exposes at least a portion of said upper surface of said raised portion of said substrate; and

a buffer layer of $\text{Al}_x\text{Ga}_{1-x}\text{N}$ where $0 \leq x \leq 1$ within said mask window; and

10 an overgrown epitaxial layer selected from the group consisting of gallium nitride and Group III nitride alloys of gallium nitride extending upwardly from said mask windows and laterally over said trench and across said mask .

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FIG. 1.FIG. 2.

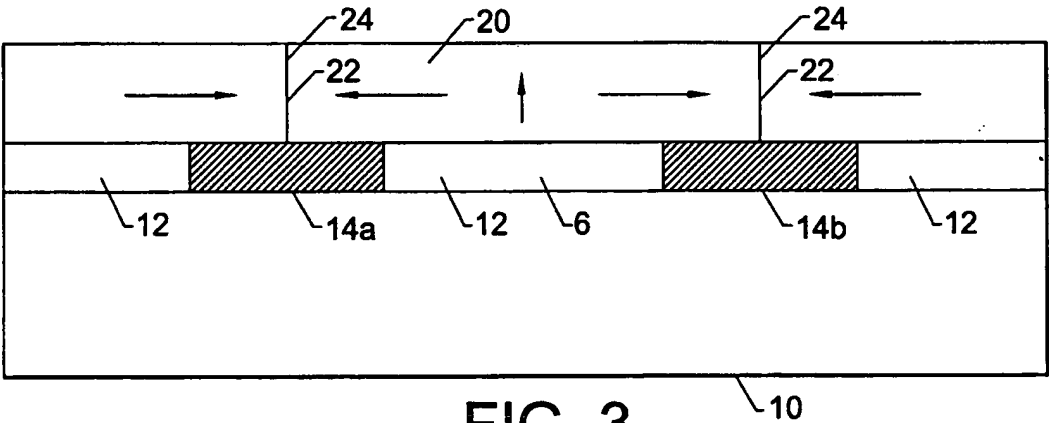


FIG. 3.

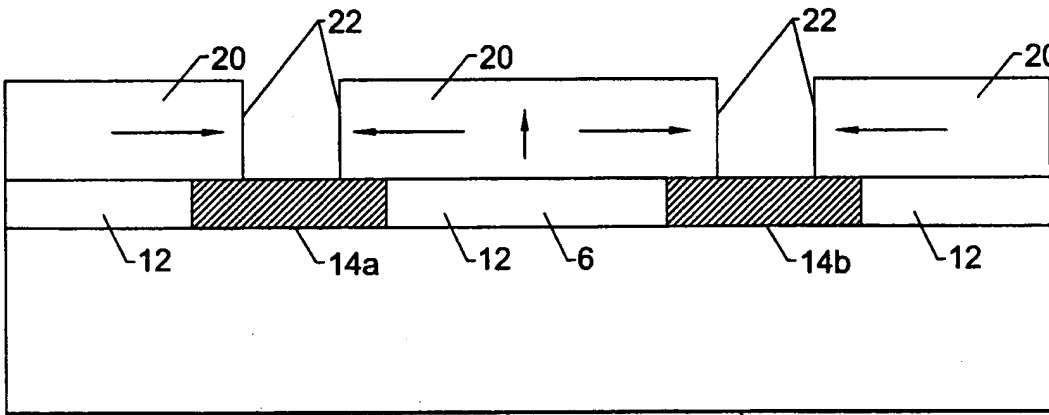


FIG. 3A.

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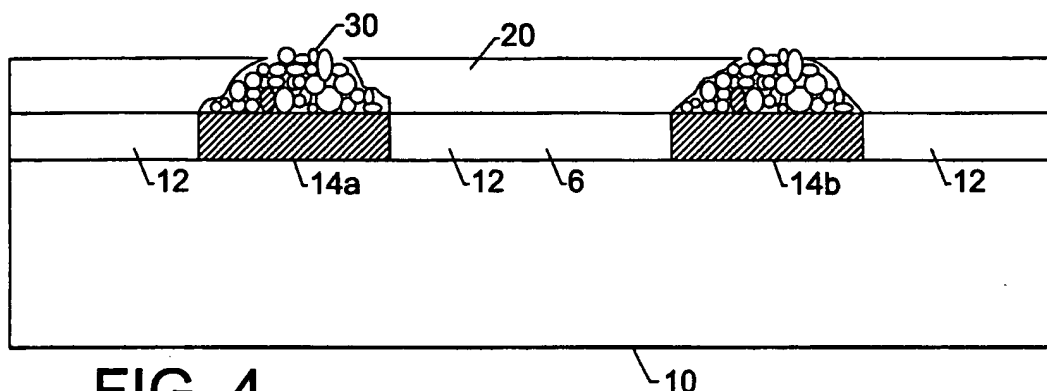


FIG. 4.

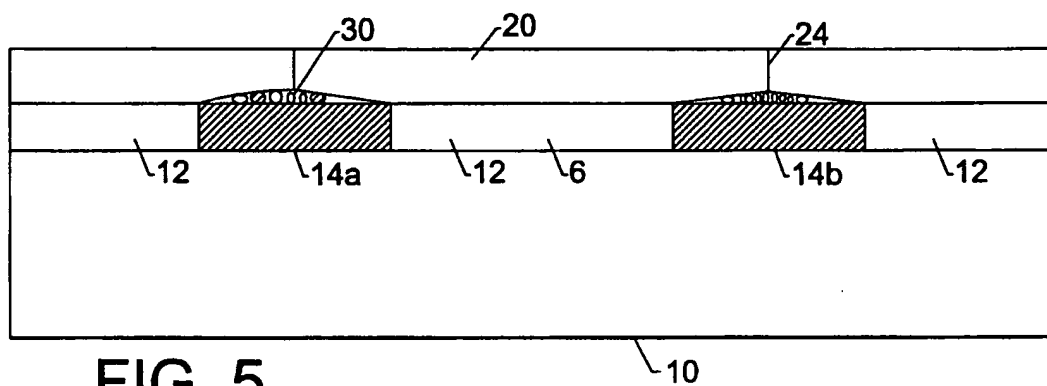


FIG. 5.

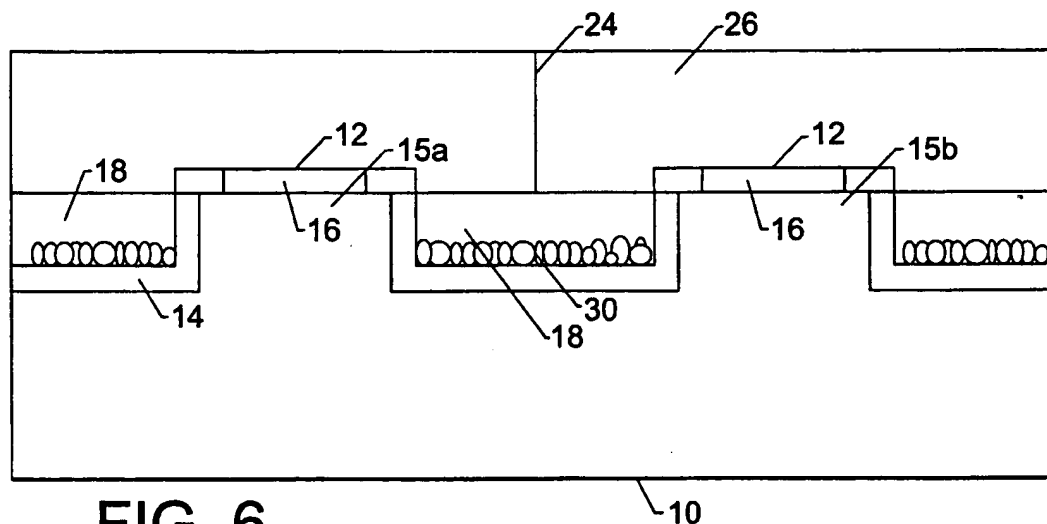


FIG. 6.

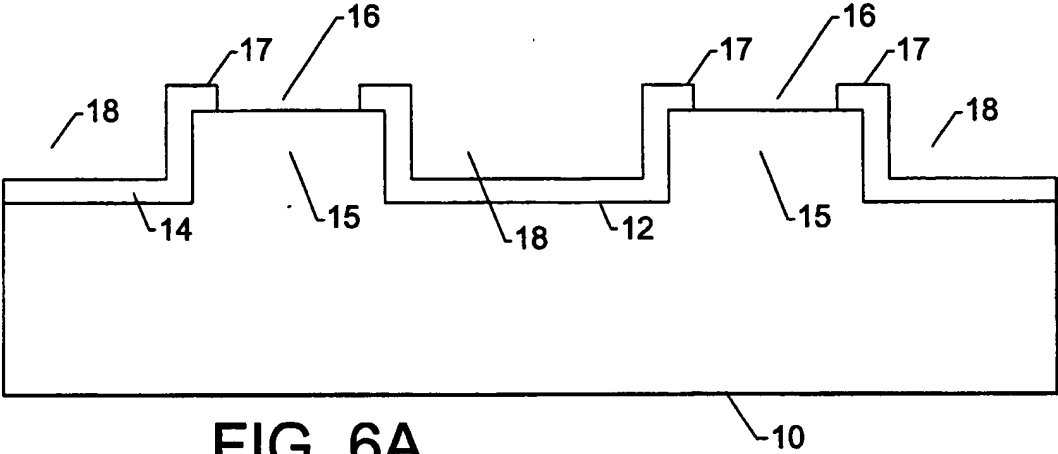


FIG. 6A.

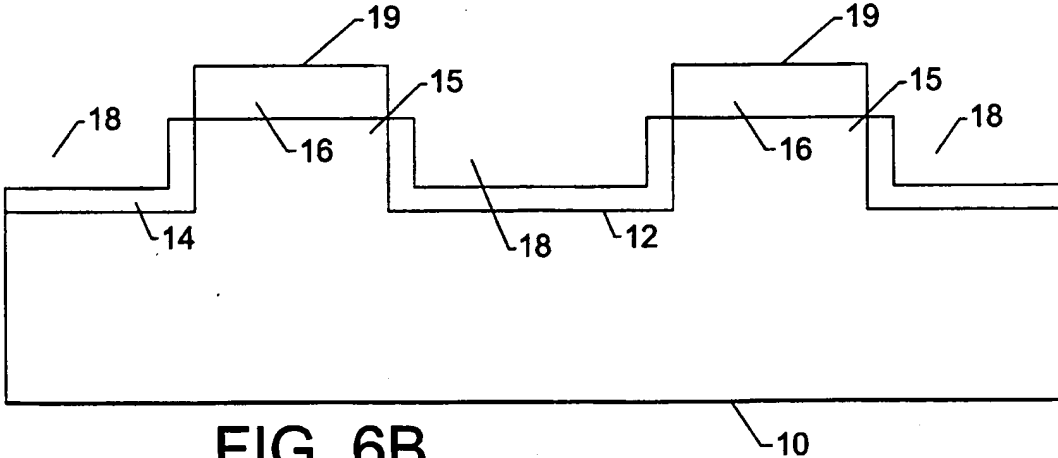


FIG. 6B.

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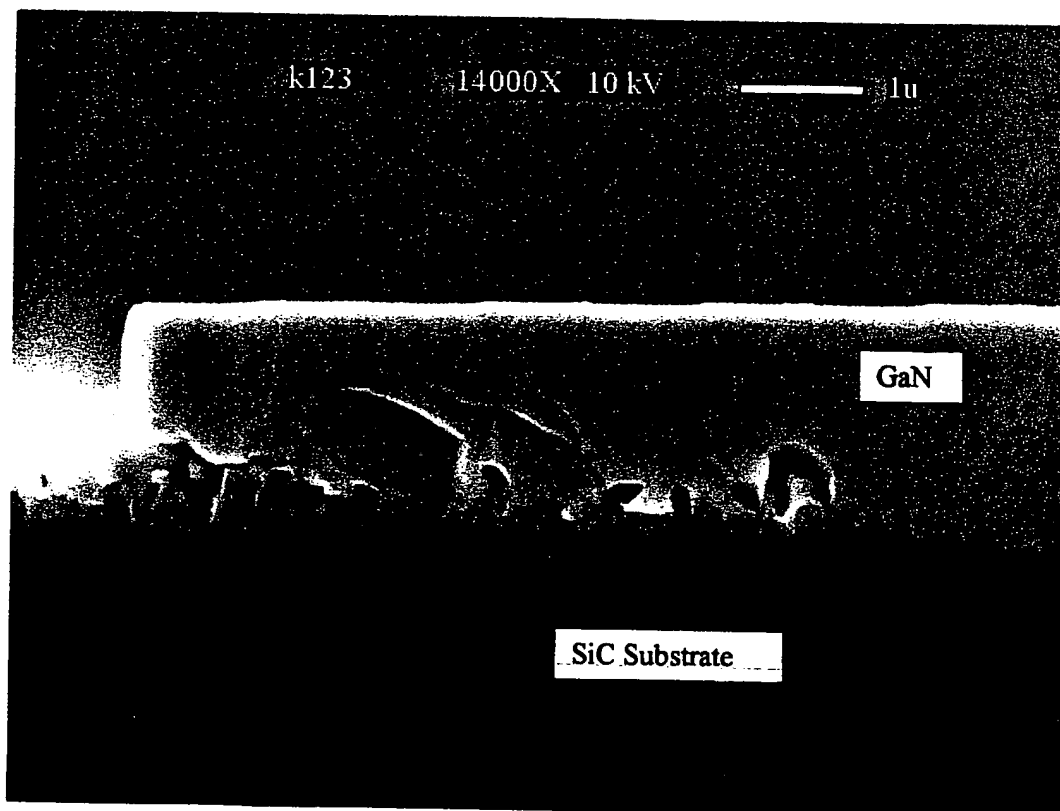


FIG. 7.

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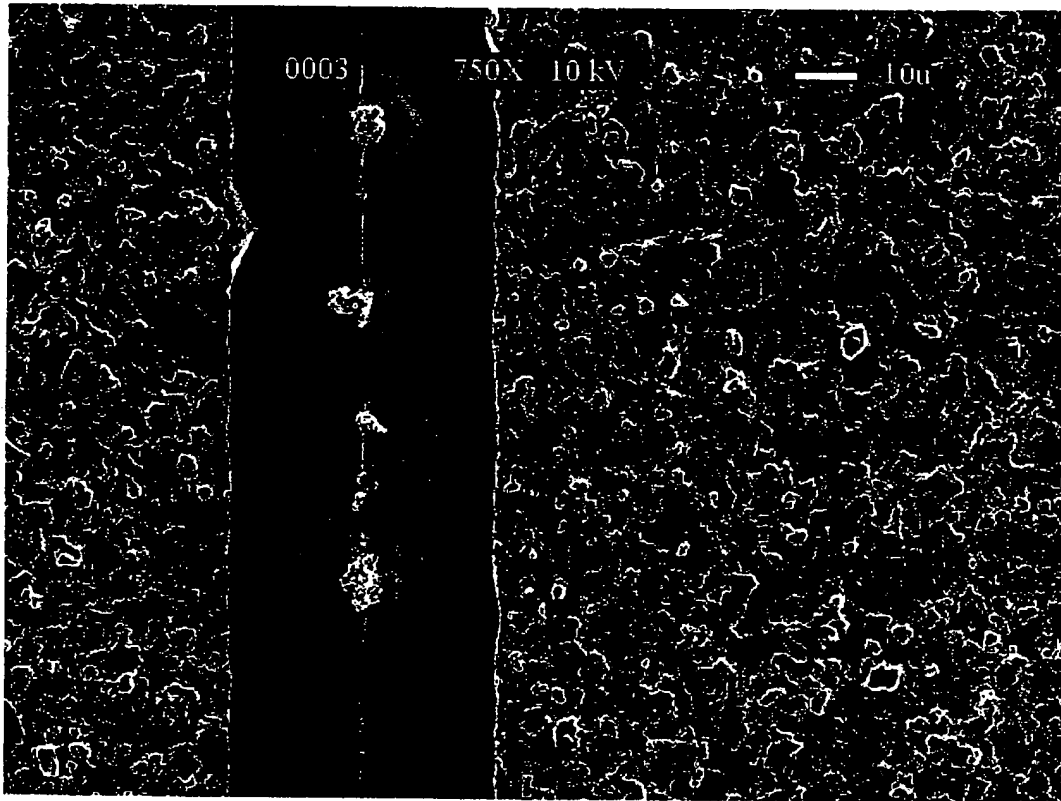
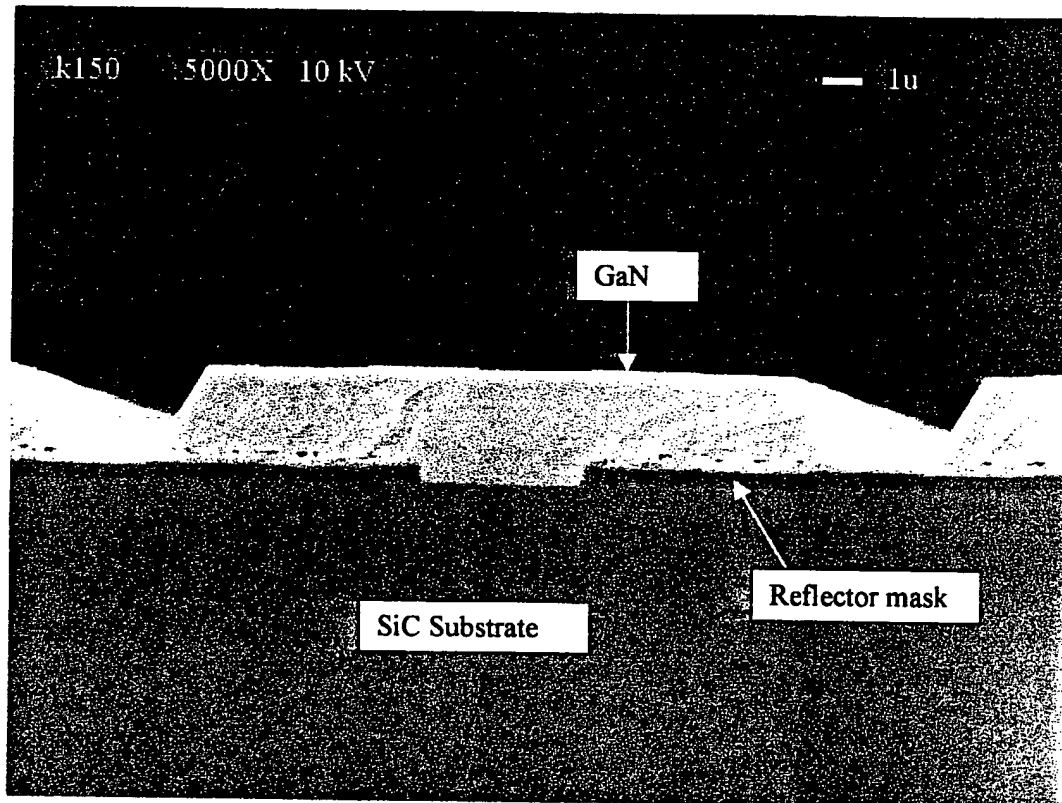
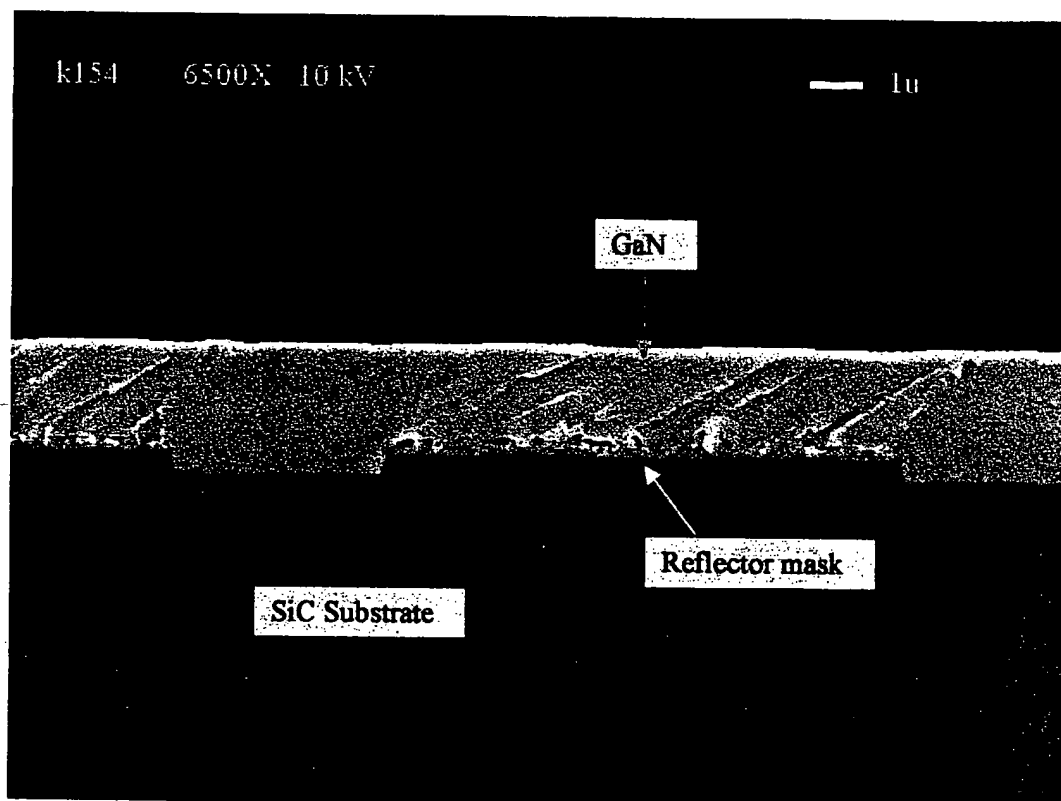


FIG. 8.

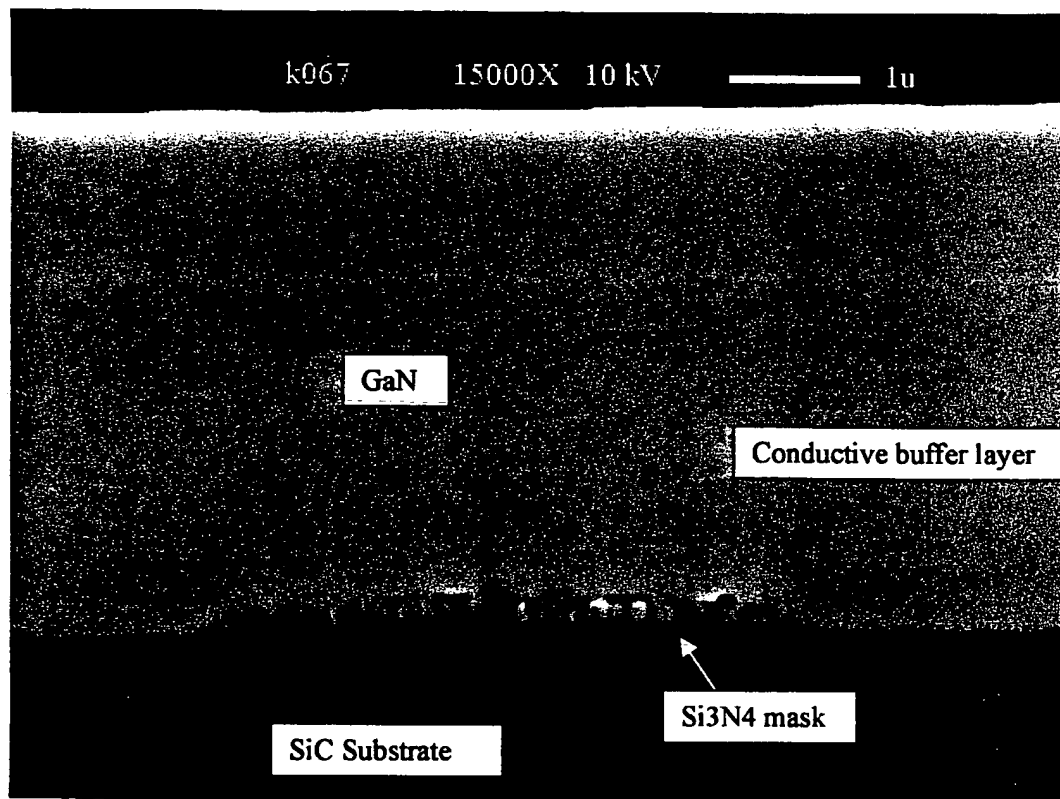
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FIG. 9.

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FIG. 10.

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FIG. 11.

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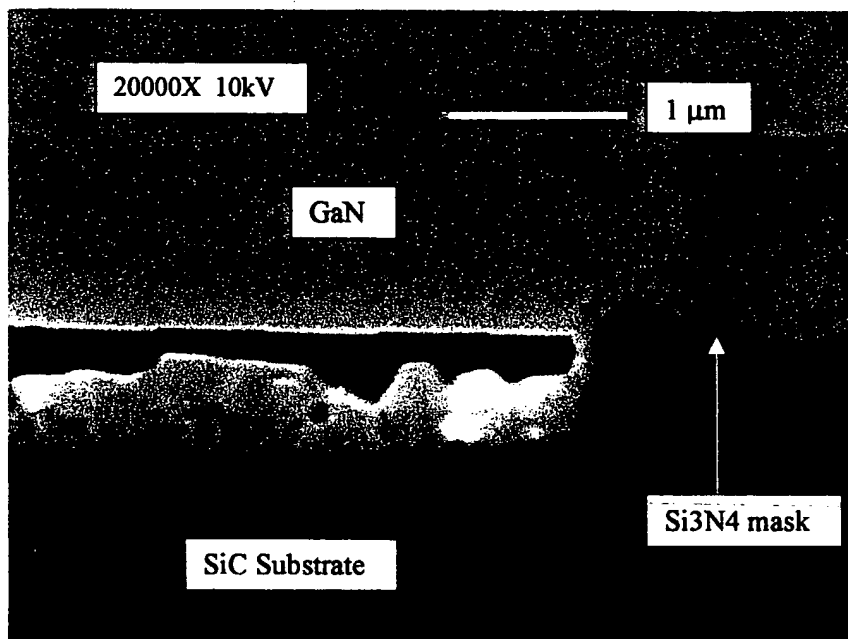


FIG. 12.

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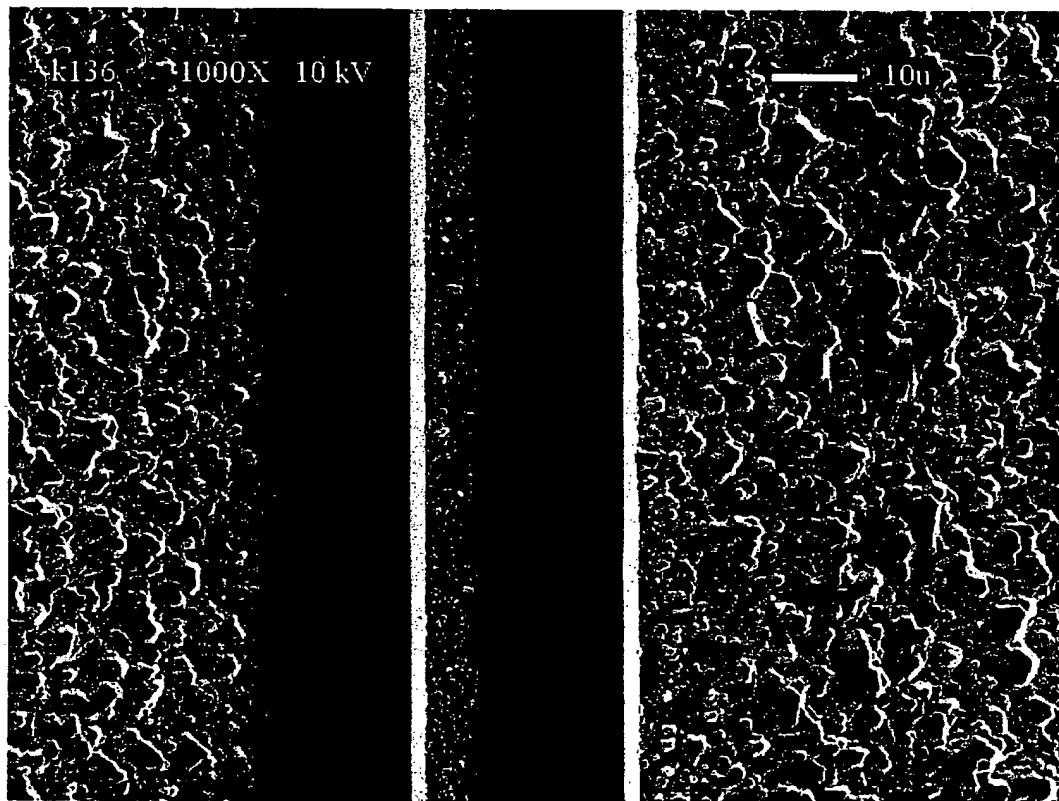


FIG. 13.

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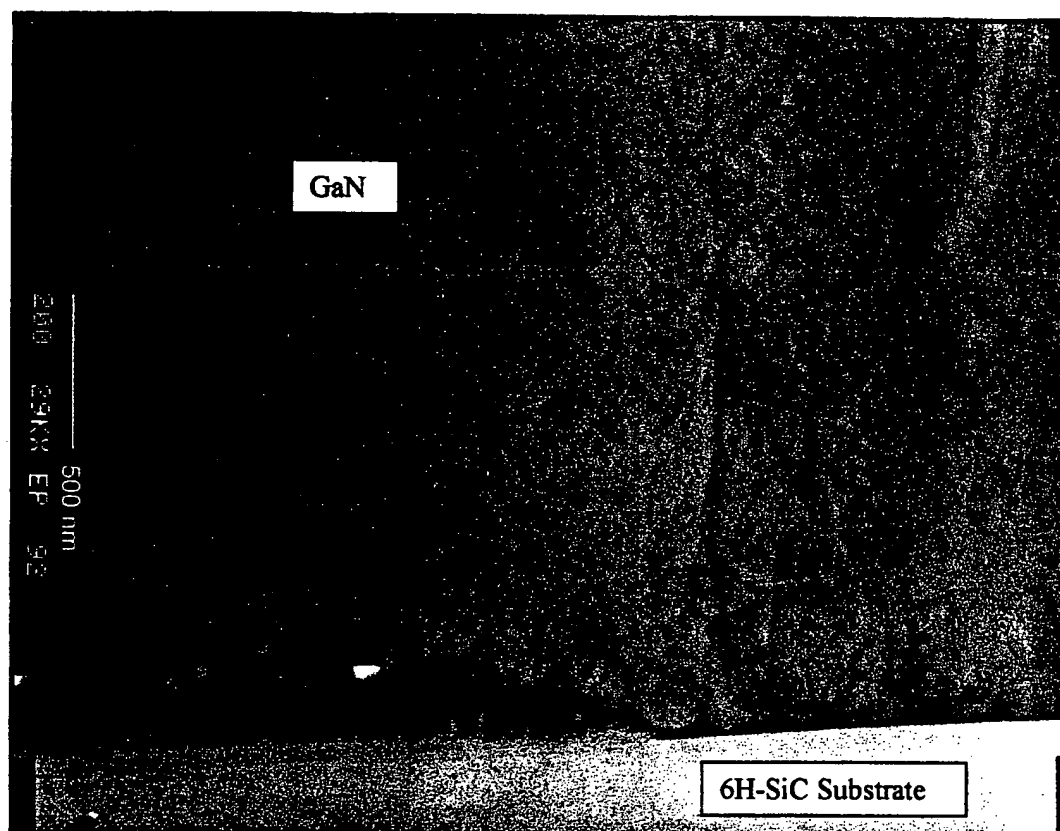
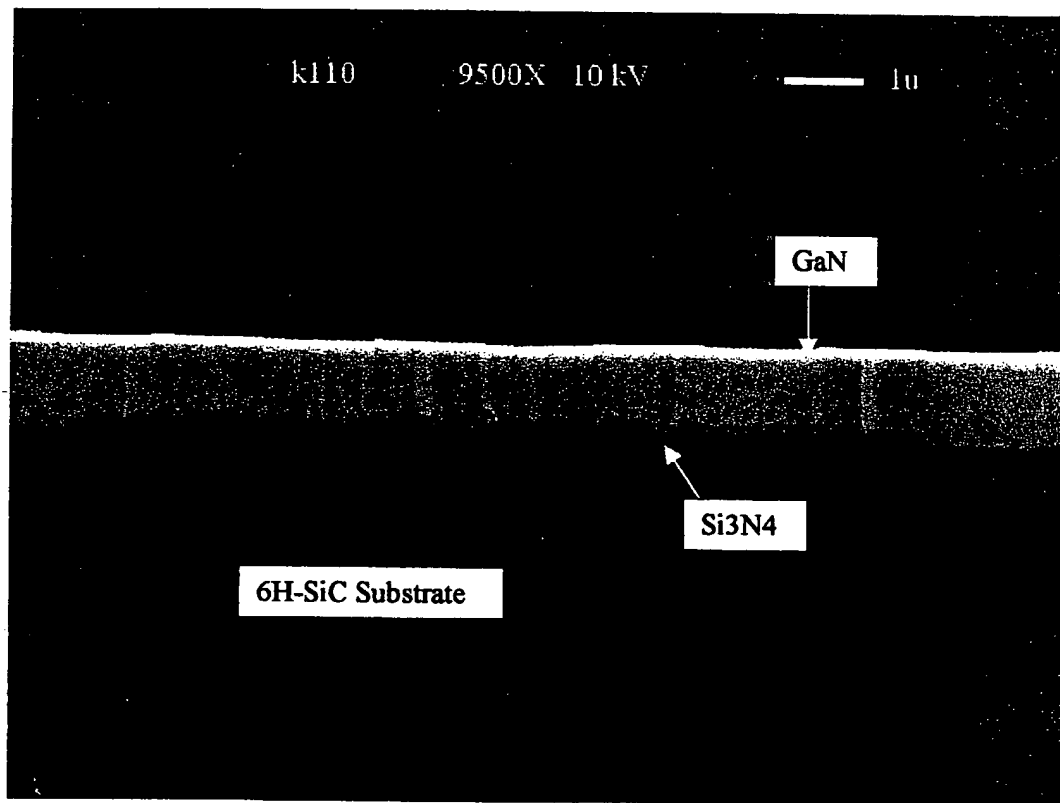


FIG. 14.

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FIG. 15.

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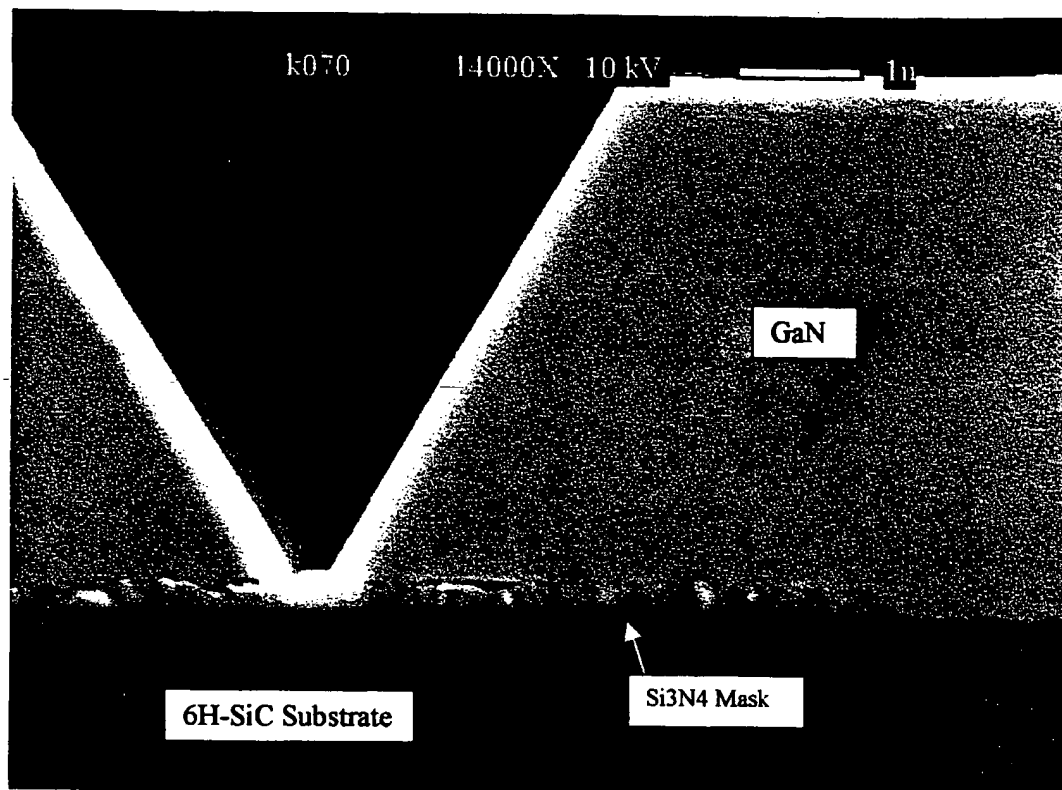


FIG. 16.

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 00/28056

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H01L21/20 H01L21/205

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 H01L C30B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

INSPEC, COMPENDEX, EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	MARX D ET AL: "Selective area growth of GaN/AlN heterostructures" JOURNAL OF CRYSTAL GROWTH, vol. 189-190, June 1998 (1998-06), pages 87-91, XP004148481 ISSN: 0022-0248	1,11,17, 24,25, 70,74, 75,77-80
A	the whole document --- -/--	27

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents:

- *A* document defining the general state of the art which is not considered to be of particular relevance
- *E* earlier document but published on or after the international filing date
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- *O* document referring to an oral disclosure, use, exhibition or other means
- *P* document published prior to the international filing date but later than the priority date claimed

- *T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- *X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- *Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
- *&* document member of the same patent family

Date of the actual completion of the international search

2 February 2001

Date of mailing of the international search report

20/02/2001

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Authorized officer

Köpf, C

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 00/28056

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	<p>PATENT ABSTRACTS OF JAPAN vol. 1999, no. 02, 26 February 1999 (1999-02-26) & JP 10 312971 A (NEC CORP), 24 November 1998 (1998-11-24)</p> <p>abstract -& JP 10 312971 A (NEC CORP) 24 November 1998 (1998-11-24) paragraph '0111! - paragraph '0123!; figure 4</p> <p>---</p>	<p>1,7-11, 18, 20-22, 24-27, 34-38, 40,70, 74-81,91</p>
A	<p>WO 99 23693 A (SUMITOMO ELECTRIC INDUSTRIES LTD) 14 May 1999 (1999-05-14)</p> <p>---</p> <p>-& EP 1 041 610 A (SUMITOMO ELECTRIC INDUSTRIES LTD) 4 October 2000 (2000-10-04) paragraph '0055! - paragraph '0063!; figures 6,7</p> <p>---</p>	<p>1,2, 8-12, 20-22, 25-27, 29,34, 36,37, 70,74, 75,77, 78,80,81</p>
A	<p>DUPUIS R D ET AL: "Selective-area and lateral epitaxial overgrowth of III-N materials by metalorganic chemical vapor deposition" JOURNAL OF CRYSTAL GROWTH, vol. 195, no. 1-4, December 1998 (1998-12), pages 340-345, XP004154285 ISSN: 0022-0248</p> <p>the whole document</p> <p>---</p>	<p>1-4,6, 11-14, 16,17, 24,26, 27, 29-31, 33,34, 40,70, 74,75, 77-81</p>
A	<p>KUNG P ET AL: "Lateral epitaxial overgrowth of GaN films on sapphire and silicon substrates" APPLIED PHYSICS LETTERS, vol. 74, no. 4, 25 January 1999 (1999-01-25), pages 570-572, XP000805771 ISSN: 0003-6951 the whole document</p> <p>---</p>	<p>1-3,5, 11-13, 15,17, 25-27, 29,30, 32,34, 70,74, 75,77-81</p>
A	<p>US 4 971 928 A (FULLER BRIAN K) 20 November 1990 (1990-11-20)</p> <p>the whole document</p> <p>---</p>	<p>1,11, 70-75, 80,81</p>
	<p>---</p> <p>-/--</p>	

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 00/28056

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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